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GOES-16 ON-ORBIT DUAL ISOLATION PERFORMANCE CHARCATERIZATION RESULTS

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ABSTRACT

The Geostationary Operational Environmental Satellite-R Series (GOES-R) is the first of the next generation geostationary weather satellites. GOES-R successfully launched on November 19, 2016 and renamed GOES-16 upon entering geostationary orbit. Subsequently, GOES-16 post-launch testing began. This paper presents the GOES-16 Satellite Dynamic Interaction Characterization results for the Earth Pointed Platform (EPP) stowed, referred to as the Reaction Wheel Assembly (RWA) Isolation Only configuration, and deployed, referred to as the Dual Isolation configuration. GOES-R represents a quantum increase in Earth and solar weather observation capabilities, with 4 times the resolution, 5 times the observation rate, and 3 times the number of spectral bands for Earth observations. With the improved resolution, comes the instrument suite's increased sensitivity to disturbances over a broad spectrum 0-512 Hz. Sources of disturbance include reaction wheels, thruster firings for station keeping and momentum management, gimbal motion, and internal instrument disturbances. To minimize the impact of these disturbances, the baseline design included an EPP, a stiff optical bench to which the two nadir pointed instruments are collocated together with the Guidance Navigation & Control (GN&C) star trackers and Inertial Measurement Units (IMUs). The EPP is passively isolated from the spacecraft bus with Honeywell D-Strut isolators providing attenuation for frequencies above ~5 Hz in all six degrees-of-freedom. To reduce the risk of wheel disturbances impacting performance, a secondary passive isolation system manufactured by Moog/CSA Engineering was incorporated under each of the six 160 Nms reaction wheels, tuned to provide attenuation at frequencies above ~50 Hz. Integrated wheel and isolator testing was performed on a Kistler table at NASA Goddard Space Flight Center. Pre-launch Satellite Dynamic Interaction Characterization high-fidelity simulations and ground testing were conducted to evaluate jitter performance for two cases: 1) deployed EPP and reaction wheel (Dual Isolation) and 2) EPP hard mounted (RWA Isolation Only) to the spacecraft. A comparison of pre-launch to post-launch Satellite Dynamic Interaction Characterization results are also presented in this paper.

1 INTRODUCTION

GOES-R successfully launched on November 19, 2016 and was renamed GOES-16 after achieving geostationary orbit. Subsequently, GOES-16 post-launch testing began. This paper presents the GOES-16 Satellite Dynamic Interaction Characterization results for the Earth Pointed Platform (EPP) stowed, Reaction Wheel Assembly (RWA) Isolation Only, and deployed, Dual Isolation, configurations. Also presented is a comparison between the on-orbit measured Dynamic Interaction Test (DIT) results, the ground DIT measurement results, and the analytical model predictions of the on-orbit DIT performance. Key pointing and jitter performance metrics were derived from the EPP mounted Earth pointing instruments and interface Engineering Diagnostic Accelerometers (EDAs). The EDA based performance metrics are used primarily in this paper for discussing the RWA Isolation Only and Dual Isolation configuration performances. The EPP mounted Inertial Measurement Units (IMU) is also used in the isolation configuration performance comparisons.

One of the most stressing disturbance environments produced by the GOES-R observatory is the combined Momentum Adjust/North-South Station-keeping (MA/NSSK) maneuver with all instruments and components operating in their nominal states including the Advanced Baseline Imager (ABI) scanning and cryocooler (CC) operating. The GOES-R series of observatories are designed to satisfy stringent INR performance during combined MA/NSSK maneuvers. The Dual Isolation configuration is designed to minimize the influence of broadband frequency spectrum vibrations resulting from these disturbances on the precision pointing and jitter sensitive EPP mounted optical instruments, while simultaneously transmitting control torques to the EPP deck for EPP/spacecraft bus tracking. The EPP and RWA isolation systems combined effect achieve the desired functional performance. The combination of EPP and RWA isolation allowed the jitter requirements to be verified by the chosen simulation-based analysis as the verification method.

GOES-R pre-launch Satellite Dynamic Interaction Characterization high-fidelity simulations and ground testing were conducted to evaluate jitter performance for two configurations: 1) deployed EPP and reaction wheel (Dual Isolation) and 2) EPP hard mounted (RWA Isolation Only) to the spacecraft. The DIT characterization was performed at Lockheed-Martin’s Waterton facility. An initial DIT was performed on January 24, 2016. During the initial DIT, the EPP launch locks were not released thereby maintaining the EPP in the stowed configuration. The nominally ~50 Hz RWA isolation system is operational for the EPP stowed configuration, which leads to this configuration being referred to as the RWA Isolation Only configuration in the remainder of this paper. The run-for-record DIT was performed on January 25, 2016. For the run-for-record DIT, the EPP launch locks were released thereby isolating the EPP from the spacecraft bus body via the nominally ~5 Hz EPP isolation system and gravity offloading it with the Anti-Gravity Machine (AGM). In this configuration, both the EPP and the RWA isolation systems are operational which lead to this configuration being referred to as the Dual Isolation configuration in the remainder of this paper.

This paper provides an overview for the performance analysis and testing employed in the synthesis of the GOES-16 Observatory Dual Isolation configuration, beginning with simulation based analysis and component level isolation systems tests, through observatory ground dynamics interaction tests, to on-orbit dynamic interaction testing. Result comparisons between analytical model predicts and measurements are described for both ground and on-orbit test results. Comparison between ground measured and on-orbit measured results is also discussed.

2 SYSTEM PERFORMANCE ANALYSIS AND TEST

The GOES-R isolation system analysis and test cycle is illustrated in Fig. 1. The cycle includes four phases: analysis, bench level component testing, observatory level ground based DIT testing, and culminated with observatory level DIT testing on-orbit.

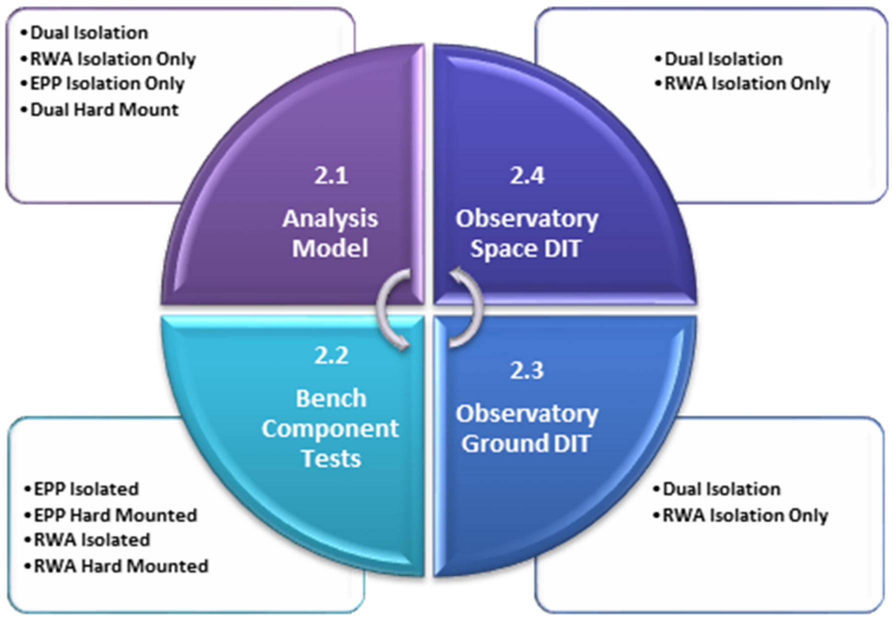


Figure 1. GOES-R Isolation System Analysis and Test Cycle [1]

2.1 Analysis Model

To support GOES-R Image Navigation & Registration (INR) systems engineering, a high-fidelity pointing and jitter simulation was assembled to evaluate EPP mounted optical instruments pointing and jitter sensitivities to the various disturbance contributors on the GOES-R observatory. Key pointing and jitter performance metrics were derived from the EPP mounted Earth pointing instruments and interface Engineering Diagnostic Accelerometers (EDAs). The EDA based performance metrics are used primarily in this paper for discussing the RWA Isolation Only and Dual Isolation configuration performances. The EPP mounted IMU is also used in the isolation configuration performance comparisons. The key disturbance sources influencing the EPP Earth pointing instruments are the reaction wheels, thruster firings, and internal instrument disturbances such as the ABI CC. The ABI CC has an active vibration suppression system which attenuates the emitted vibrations from the CC. The residual emitted vibration that remains after application of the ABI CC active vibration suppression is the disturbance of interest in this paper. The high-fidelity pointing and jitter simulation results were compared to the ground-based and on-orbit measured DIT results.

One of the most stressing disturbance environments produced by the GOES-R observatory is the combined Momentum Adjust/North-South Station-keeping (MA/NSSK) maneuver with all instruments and components operating in their nominal states including the ABI scanning and CC operating. The GOES-R series of observatories are designed to satisfy stringent INR performance during combined MA/NSSK maneuvers. This observatory capability is referred to as “operate-

through" maneuvers. During the combined MA/NSSK maneuver, the RWAs are slewing between their positive and negative maximum operating rates while the Low Thrust REAs (LTRs) and Arcjet Thrusters are simultaneously firing. The Dual Isolation configuration is designed to minimize the influence of broadband frequency spectrum vibrations resulting from these disturbances on the precision pointing and jitter sensitive EPP mounted optical instruments while commanding EPP and spacecraft bus tracking. The EPP and RWA isolation systems combined effect achieve the desired functional performance. The EPP isolation was the GOES-R baseline at the start of the program development cycle, and it was always retained. After program CDR, there was the need to switch to Honeywell RWAs [4]. The combination of EPP and RWA isolation systems allowed the observatory jitter requirements to be verified by simulation-based analysis.

The analysis and test cycle began with the development of a high-fidelity analysis model that had the flexibility to be transformed into four isolation configurations for performance assessment and model credibility confirmation. Details of the modeling and analysis approach have been presented by Chapel, et al [2]. The high-fidelity simulation was exercised to evaluate performance of four isolation configurations and to gain insight into the effectiveness of isolation. As displayed in the upper-left quadrant of Figure 1, the four isolation configurations are:

- Dual Isolation
- RWA Isolation Only
- EPP Isolation Only
- Dual Hard Mount

The GOES-R high-fidelity observatory pointing control and jitter simulation was developed from high-fidelity structural dynamics component models, integrated into a system level structural model using component modes synthesis. The modal content of the combined observatory structural model was adequate to characterize observatory flexibility up to 512 Hz. The model was augmented with physics-based nonlinear phenomenon and multi-rate control loops. The model implements disturbances resulting from RWAs including gyrodynamics, thruster firings, thermal snaps, solar array articulation, and others. The high-fidelity observatory pointing control and jitter simulation was used to analytically verify GOES-R on-orbit pointing control and jitter performance requirements. The integrated model includes:

- All instrument models: Advanced Baseline Imager, Geostationary Lightning Mapper, Solar Ultraviolet Imager, Extreme Ultra Violet / X-Ray Irradiance Sensors, Space Environment In-Situ Suite
- Honeywell EPP and isolation mount system
- Reaction wheels and reaction wheel brackets with isolation
- Deployed magnetometer boom and magnetometers
- Deployed solar array wing, antenna wing, and X-Band antenna reflector
- Propellant slosh dynamics
- Engineering Diagnostic Accelerometers models
- Nadir instrument Line-of-Sight (LOS) models

The high-fidelity observatory jitter simulation development yielded a model with nearly ten-thousand states, employing nonlinear high-fidelity friction components, and hybrid-time. There are six EDAs mounted on the EPP to measure accelerations at the ABI and Geostationary Lightning Mapper (GLM) instrument interfaces on-orbit. The location of the EPP mounted EDAs are depicted in Fig. 2. One EDA is aligned with the observatory X-axis, another is aligned with the observatory Y-axis, with the remaining four EDAs being distributed across the EPP instrument mounting interface and aligned with the observatory Z-axis. They are modeled in the high-fidelity observatory jitter model. The frequency spectrum produced by the EDA models serve as the performance metrics. High-level sensitivity analyses based on isolation configuration modifications lends credibility to the analysis model. These configuration changes confirmed that the model behaved in a predetermined expected manner. The model isolation configuration sensitivity analysis also confirmed the model's robustness to credible model changes. For the EDA based performance results that follow, envelope plots over all EDA measurement results are presented.

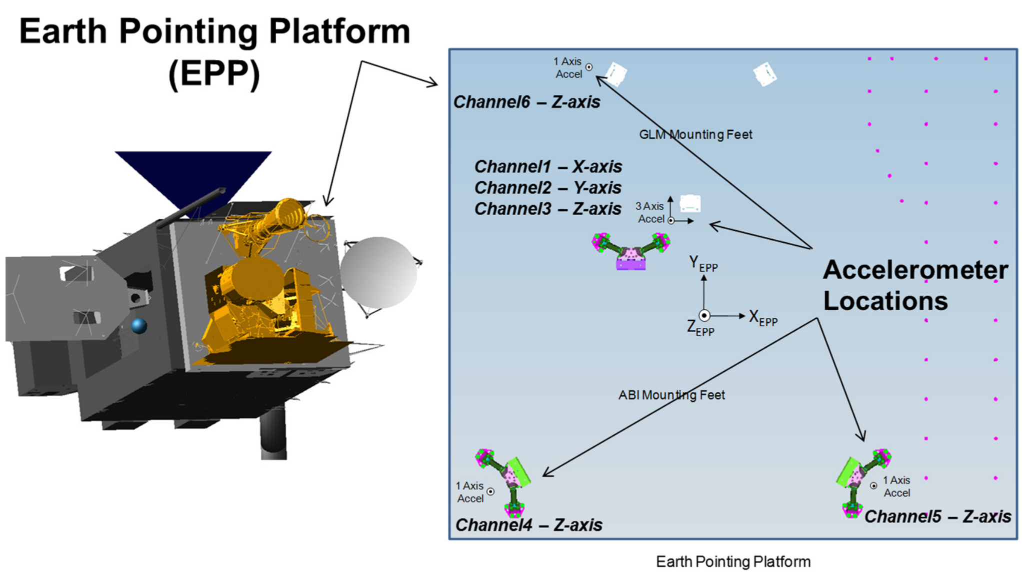


Figure 2 EDA Locations

2.2 Bench Component Tests

Some key isolation component tests are displayed in the lower left quadrant of Fig. 1. These entail the EPP and RWA isolation systems testing. The GOES-R program established requirements for the EPP isolator based upon simulations of the vehicle disturbances and the transmissibility of the structure. Because of the uncertainties inherent in the early phases of the design effort, these models used to derive the isolation requirements included conservative modeling assumptions. The resulting requirements include a 2nd-order roll-off with a center frequency of ~5 Hz, and span a frequency range from 1 Hz to 30 Hz. The peaking of the isolation system is limited to less than 6 dB. These requirements apply to each of the six degrees-of-freedom, and apply over the operational temperature range. The GOES-R program undertook a full qualification effort for the EPP and the EPP isolation system. To demonstrate acceptable stability and isolation performance and to validate the simulation models, an engineering design unit (EDU) EPP with six D-Strut isolators arranged in a flight-like configuration was assembled and tested at Honeywell's facilities.

The RWA isolation system was designed by Moog CSA to directly isolate the RWA disturbance source and to work in concert with the EPP isolation system. All six GOES-R RWA wheels were isolated independently; each by a system of three isolators positioned between the RWA adapter and pedestal. As with all isolation systems, the ability to cluster the six isolation modes into a frequency band that does not: 1) couple with wheel disturbance frequencies and, 2) interfere with spacecraft bus resonances that could exacerbate the LOS jitter issues already established, is key. The RWA isolation system complied with the minimum frequency requirement of 45 Hz, met the damping requirements of 3% critical damping in the suspension modes, and was tuned to provide 6-DOF isolation. The required attenuation beyond the break frequency was achieved per the specification.

2.2.1 EPP Isolation

To attenuate high frequency disturbances to the Earth-observing instruments from the spacecraft bus, including reaction wheel disturbances, gimbal disturbances, and disturbances from the sun-pointed instruments, the EPP is passively isolated from the spacecraft bus with flight-proven Honeywell D-Strut isolators arranged in a modified Stewart platform configuration [3]. The isolation system provides attenuation for frequencies above ~5 Hz in all six degrees-of-freedom. The mounting geometry and the strut parameters have been optimized to provide balanced isolation performance in all six degrees-of-freedom.

To assess the isolator performance impacts of parasitic shunts across the isolation interface, flight-like harnessing and multi-layer insulation blanketing were included in the test configuration. Tests were run with and without the shunts present. The transmissibility results of the EPP EDU testing are shown in Fig. 3 for the X and Y translation axes. As can be seen in the figure, the requirements are met for the EPP isolation with and without the shunts included. However, the shunts clearly affect the performance of the isolation system, and therefore cannot be neglected in the simulation models. The shunts are not symmetric with respect to the EPP layout, so some axes are affected more than others. Because of the impacts of the shunts on the overall dynamics, additional testing was performed to more accurately capture the shunts' effects. The results have been included in the high-fidelity simulation models of the EPP isolation.

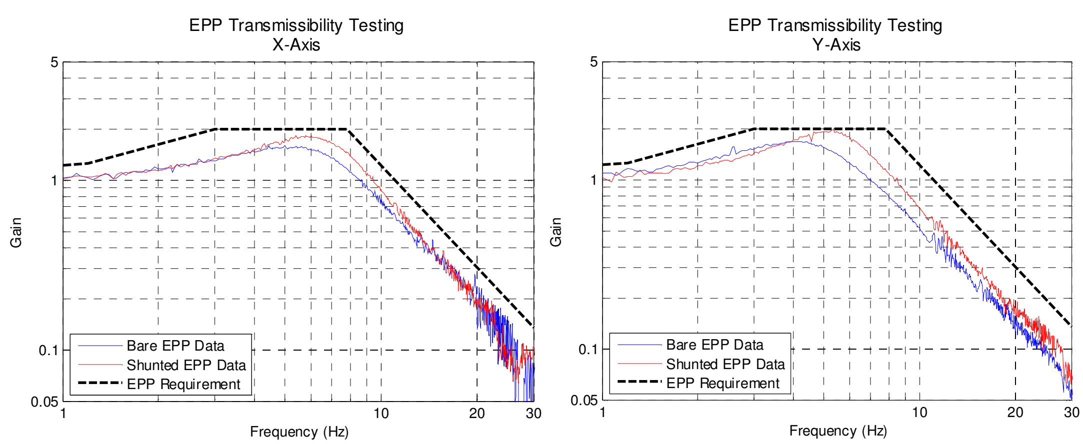
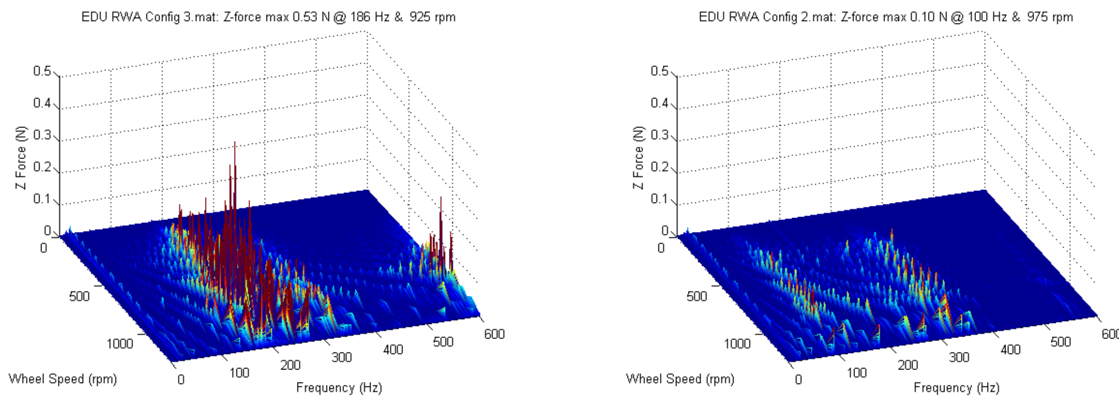


Figure 3. GOES-R EPP Isolation Requirements and Observed Performance from EDU Testing [4]

2.2.2 RWA Isolation

As Honeywell completed EDU RWA testing and Moog/CSA completed EDU isolator testing, the

separate elements were shipped to NASA Goddard for integrated testing on a Kistler Table. The RWA isolation system configuration was compared to the results obtained from a hard mount equivalent configuration. The two configurations were identical with the exception that the RWA was mounted on the Moog/CSA isolators for one configuration and had the RWA hard mounted for the other. The hard mounts were designed to keep the RWA center-of-gravity at exactly the same location relative to the Kistler table. The measured Z-axis (RWA spin axis) force disturbances over the nominal operational wheel speed range 0-1300 RPM are shown in Fig. 4 for both the hard mounted and isolated configurations. The improvement in performance over the 200-300 Hz band is consistent with that measured by the Moog CSA modal testing.

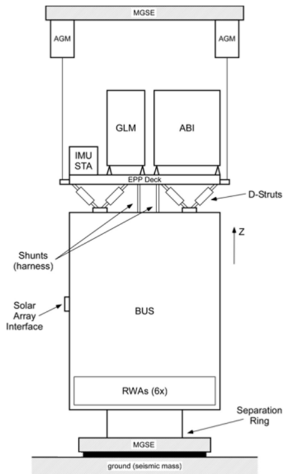


a) Hard Mount Configuration **b) Isolated Configuration**

Figure 4. RWA Hard Mount vs Isolated NASA Goddard Kistler Table Induced Vibration Results

2.3 Observatory Ground DIT

The right-hand quadrants of Fig. 1 display the observatory level isolation tests performed on the ground and in space. This system level testing included a pre-launch Dynamic Interaction Test (DIT) as well as Post Launch Testing (PLT). The pre-launch DIT measures structural dynamic responses due to instrument and satellite disturbance sources to validate the dynamic models of the satellite, characterizing the integrated spacecraft dynamics in a flight-like configuration for the nadir pointed ABI and GLM instruments. The DIT does not verify performance. Rather, the DIT demonstrates that observatory dynamic responses are in family with predictions, establishing confidence that the disturbance and damping elements of the system design are functioning as expected. Fig. 5 illustrates how the EPP is offloaded during the ground DIT. To achieve a flight configuration requires the use of an AGM supplied by Moog CSA Engineering. In addition to the flight EDAs, during the tests the spacecraft was instrumented with high bandwidth linear acceleration sensors collected at 2000 Hz to verify accelerations during operations with RWA and instrument disturbances.



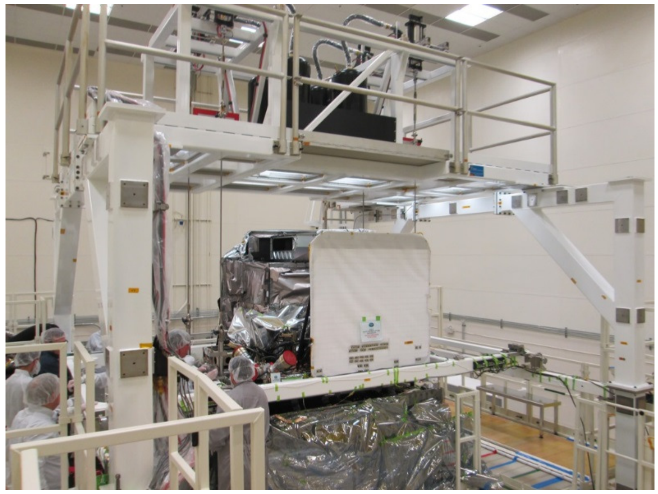


Figure 5. AGM Offloads EPP During Deployment and Pre-Launch DIT

Although various performance measurements were collected during the ground DIT, this paper focuses on the results obtained from the EDAs, primarily, and the IMU for the ground and on-orbit DITs. For the EDA based performance results that follow, envelope plots over all EDA measurement results are presented.

The GOES-R ground DIT consisted of various test events for both the RWA Isolation Only and the Dual Isolation configurations. The first test event was to measure the ambient background vibration disturbance environment. The results for this test event aren't included in this paper however these results were used to "noise correct" the ground DIT results included in this paper. The second test event measured the emitted vibrations sensed by the EDAs with the ABI operational, including scanning and CC operating. This second test event was performed for both primary and redundant (Red) ABI CC operations. For the second test event, the RWAs were inactive. The third test event measured the emitted vibrations sensed by the EDAs with the RWAs operational. For this test, all six RWAs were rate swept in unison from 0 to 1100 rpm. For the third test event, the ABI was inactive.

2.3.1 Results for Isolator Performances with ABI Only Operation

Testing occurred over two nights around midnight to minimize extraneous vibration disturbances from perturbing measurement results. An initial DIT was performed on January 24, 2016. For this DIT, the test article and supporting equipment were in their nominal operational state in agreement with the run-for-record test state. This included having the AGMs at their nominal pressure values for gravity offloading the EPP on the nominally 5 Hz EPP isolation system in preparation of EPP launch lock release. However during the initial DIT, the EPP launch locks were not released thereby maintaining the EPP in the stowed configuration. The nominally ~50 Hz Reaction Wheel Assembly (RWA) isolation system is operational for the EPP stowed configuration which leads to this configuration being referred to as RWA Isolation Only. The run-for-record DIT was performed on January 25, 2016. For this test, the test article and supporting equipment were in their nominal state of performance and operation for actual testing. This included having the AGMs at their nominal pressure values for gravity offloading the EPP on the nominally ~5 Hz EPP isolation system in preparation of EPP launch lock release. For the run-for-record DIT, the EPP launch locks were released thereby isolating the EPP from the spacecraft bus body via the EPP isolation system and

gravity offloading it with the AGMs. In this configuration, both the EPP and RWA isolation systems are operational which leads to this configuration being referred to as the Dual Isolation configuration.

The analytical and measured results, processed into performance readable form, for the RWA-Isolation Only and the Dual Isolation configurations are displayed in Fig. 6-9. For these results, only the ABI Redundant CC was operating. Germaine to our discussions here are the jitter requirements, cast in terms of the linear translational acceleration Shock Response Spectra (SRS) at the instrument interfaces. The broad frequency range requirement specifications are displayed in the figures. Two levels are shown, General Interface Requirements Document (GIRD) [5] and Payload Resource Allocation Document (PRAD) [6]. The instruments are designed to meet their performance requirements in the presence of the higher GIRD levels. The spacecraft is designed to produce disturbances no greater than the lower PRAD levels. The difference between the two levels is government reserve.

As can be seen from the plots in this set, the analytical (SIM) and ground DIT measured results show favorable correlations. The ground DIT results do show evidence of higher first harmonics amplitudes relative to the analytical results. A sensitivity analysis of CC harmonic amplitudes as a function of interface impedance shows this result to be within expectations. Note that the ABI CC first couple of harmonics amplitude are reduced for the Dual Isolation configuration relative to the RWA Isolation Only configuration. This is seen to be in agreement with the predicted behavior between these two configurations. The stated findings are applicable for both the ABI primary and redundant CCs. The jaggedness seen in the measured ground DIT results are due to "noise correcting" the measured data to somewhat factor out the measured ambient background vibration disturbance effects.

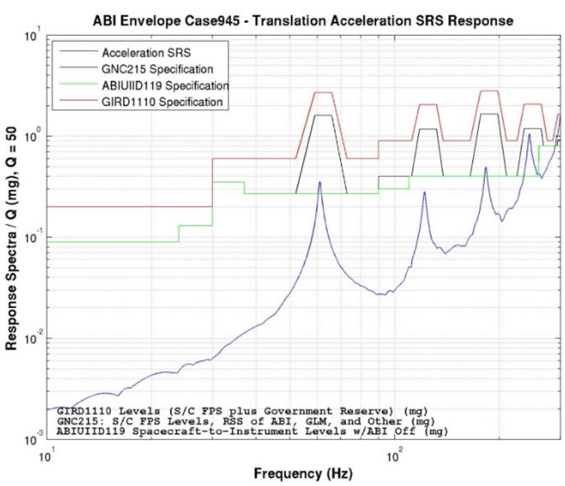


Figure 6. RWA Isolation Only, ABI Only, Red CC (SIM)

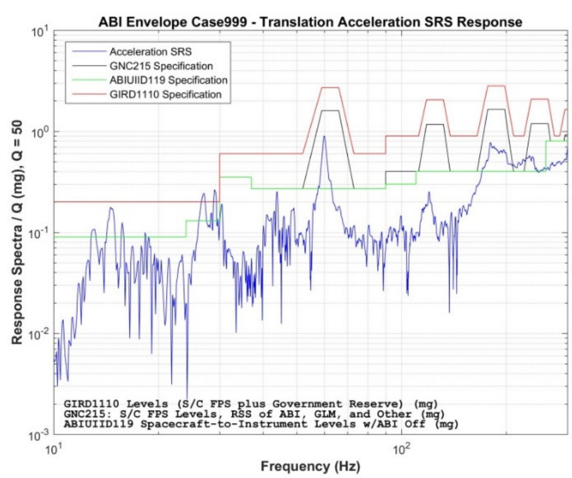


Figure 7. RWA Isolation Only, ABI Only, Red CC (Noise Corrected DIT Measurement)

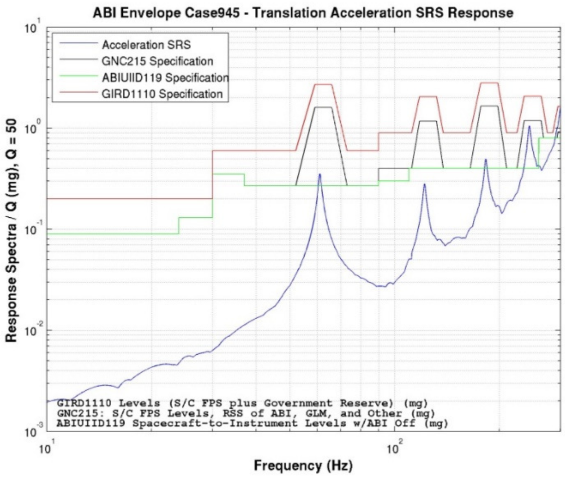


Figure 8. Dual Isolation, ABI Only, Red CC (SIM)

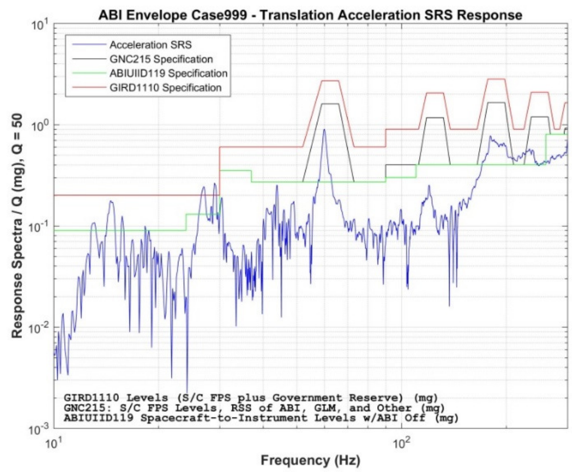


Figure 9. Dual Isolation, ABI Only, Red CC (Noise Corrected DIT Measurement)

2.3.2 Results for Isolator Performances with RWAs Only Operation

The analytical and measured results for the RWA-Isolation Only and the Dual Isolation configurations when only the RWAs are operating are displayed in Fig. 10-13. As can be seen from the plots in this set, the analytical and ground DIT measured results show somewhat favorable correlations. For this set of results, it is expected that the analytical correlation to the measured results is not strong. This follows given that the on-orbit designed analytical model was not tuned for the ground DIT environment so idealities that are true for the on-orbit space environment are not so for the ground DIT environment. The primary ideality that exists on-orbit but is violated for the ground test is the free-free spacecraft bus body behavior. For the ground test, the spacecraft bus was not structurally isolated from the lab environment but was essentially hard mounted to it via the spacecraft carrying fixture. This interface coupling alone introduces a substantial mismatch between the on-orbit flight based analytical model and the true mechanical coupling that existed for the ground DIT. For the EPP mounted disturbances and measurements, this mechanical coupling effect is greatly reduced for the Dual Isolation (deployed EPP) configuration. In this configuration, the EPP is isolated from the spacecraft bus via the ~5 Hz EPP isolation system and gravity offloaded by the AGMs. This lessens the influence of the spacecraft bus coupling to ground. However for the spacecraft bus borne disturbance transmissions to the EPP mounted EDA sensors, the bus structure coupling to ground is not flight-like. Not only do the spacecraft bus borne disturbances see the structure due to the bus but it also sees the spacecraft bus-to-ground coupling structure, a path that is nonexistent in the analytical model. Because of this, differences between the analytical predicts of RWA ground DIT measurements to actuals is to be expected. Given this difference between the analytical model and the ground DIT interface environment, the comparison between the two results is not too bad. The jaggedness seen in the measured ground DIT results are due to “noise correcting” the measured data to somewhat factor out the measured ambient background vibration disturbance effects. When compared with the analytical results, the influence of the broadband background noise is evident in the ground DIT measured results especially in the lower frequency range. The on-orbit equivalent results do not display this characteristic.

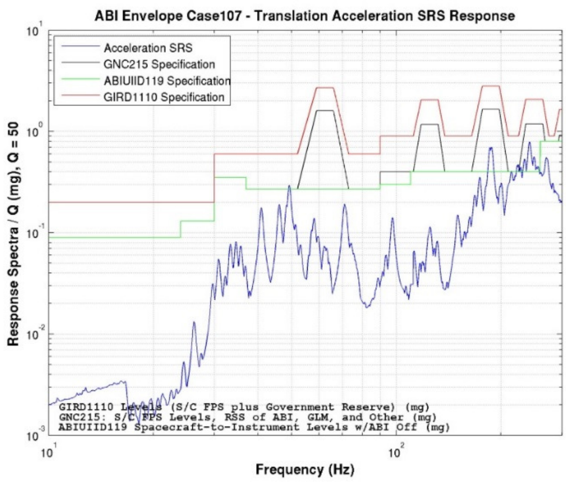


Figure 10. RWA Isolation Only, RWA Only (SIM)

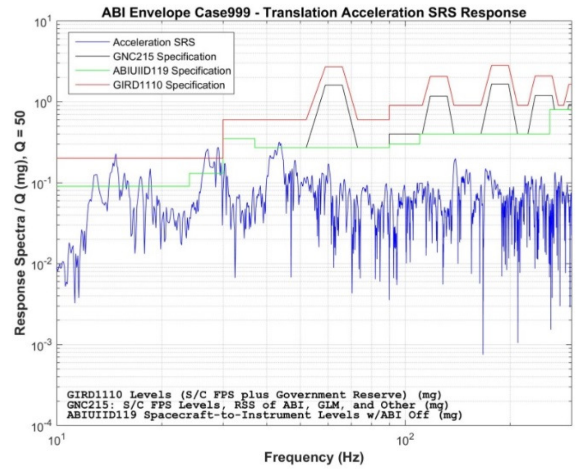


Figure 11. RWA Isolation Only, RWA Only (Noise Corrected DIT Measurement)

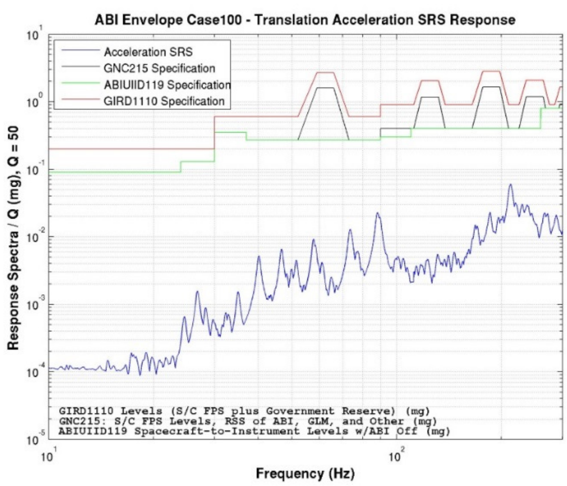


Figure 12. Dual Isolation, RWA Only (SIM)

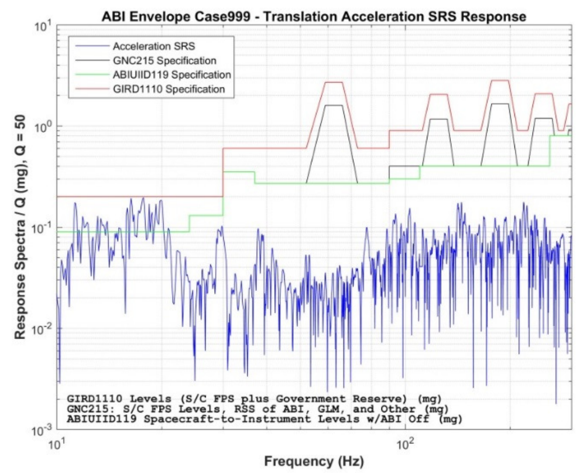


Figure 13. Dual Isolation, RWA Only (Noise Corrected DIT Measurement)

2.4 Observatory Space DIT

Following launch, GOES-16 was subjected to 6 months of extensive testing prior to being put into operational service. The testing includes: 1) characterization of the disturbance environment at the ABI and GLM interfaces using the EDAs (space DIT) and 2) an assessment of the quality of the actual ABI and GLM data products. A key element of this testing is that data was collected both prior to the release of the EPP launch locks (RWA Isolation Only), and following EPP deployment (Dual Isolation). As the analysis suggested, mission performance requirements are satisfied for both the Dual Isolation and RWA Isolation Only configurations, with the Dual Isolation configuration generally enhancing performance margins. The Dual Isolation configuration provides performance robustness against degraded performing vibration emitting sources over the mission lifetime.

The GOES-16 observatory combined MA/NSSK stressing disturbance environment maneuver is the focus of the results presented in this paper for the on-orbit DIT. During the combined MA/MSSK maneuver, the RWAs are slewing between their positive and negative maximum operating rates while the LTRs and Arcjet Thrusters are simultaneously firing. Also, all instruments and components are operating in their nominal states, which includes the ABI scanning and CC operating, accentuating the operational disturbance environment. The GOES-R series of observatories are designed to satisfy stringent INR performance requirements during combined MA/NSSK maneuvers.

2.4.1 EDA Based Results

A comparison of pre-launch to post-launch Satellite Dynamic Interaction Characterization results may be accomplished by comparing Fig. 7, 9, 11 and 13 to, Fig. 15 and 17. Note that for the ground DIT results the ABI and RWAs were operated separately and without thruster firings whereas the on-orbit DIT result is for a combination of ABI, RWAs, LTR, and Arcjet plus other instruments and components operating simultaneously. There is strong correlation between the ABI ground DIT measured results and the on-orbit DIT measured results. The ABI on-orbit performance results are generally equivalent to or better than the ground measured results for both the RWA Isolation Only and Dual Isolation configurations. Because of the ground DIT background noise environment, the RWA operation correlation between the ground and on-orbit DIT measured results is not readily discernable, although generally the noise floor for the on-orbit result is reduced relative to the ground DIT equivalents for both the RWA Isolation Only and Dual Isolation configurations. As mentioned previously, the influence of broadband background noise is evident in the ground DIT measured results, especially in the lower frequency range, but is absent for the on-orbit equivalent results for both the RWA Isolation Only and Dual Isolation configurations, as expected.

A comparison of the analytical model results to the on-orbit measured DIT results may be performed using Fig.14-17. Common trends are evident when these results are compared. A predominant trend that is discernable in both the analytical and on-orbit measured DIT results is the reduction in the “noise floor” for the Dual Isolation configuration relative to the RWA Isolation Only configuration. This is seen to be true in general over the entire plotted frequency range but especially so for the mid-frequency range 20-60 Hz. Another common trend between the analytical model and the on-orbit measured DIT results is the reduction in the ABI CC amplitude at the CC fundamental harmonic for the Dual Isolation configuration relative to the RWA Isolation Only configuration. This was a trend seen for the ground DIT measured results as well. What is evident in the analytical EDA performance predicts is a general increase in the frequency spectrum amplitude with increasing frequency that is not as strongly evident for the on-orbit measured DIT results. The increasing amplitude behavior is generally evident for the ABI ground DIT results as well. Another difference between the analytical model results and the measured on-orbit DIT results are the ABI CC harmonic amplitudes. Fig.14-17 show the ABI CC operating at the common frequency of 62 Hz for the analytical model and the on-orbit DIT. For some CC harmonics, the analytical model amplitudes are smaller than the corresponding on-orbit DIT measured amplitudes and vice-versa for other harmonics. Generally, the analytical model and the on-orbit DIT show compatible measurement results for the simultaneous combination of ABI, RWAs, LTR, and Arcjet plus other instruments and components operating disturbance environment. The Dual Isolation configuration shows reduced “noise floor” disturbance levels generally over the entire frequency range displayed in the plots but especially so for the mid-frequency range of 20-60 Hz relative to

the RWA Isolation Only configuration.

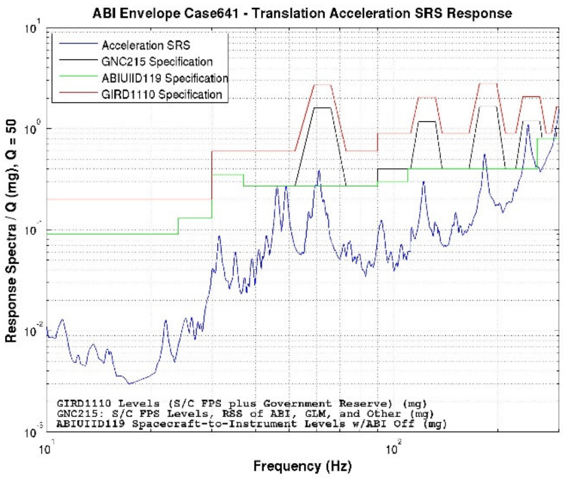


Figure 14. RWA Isolation Only, Red CC (SIM)

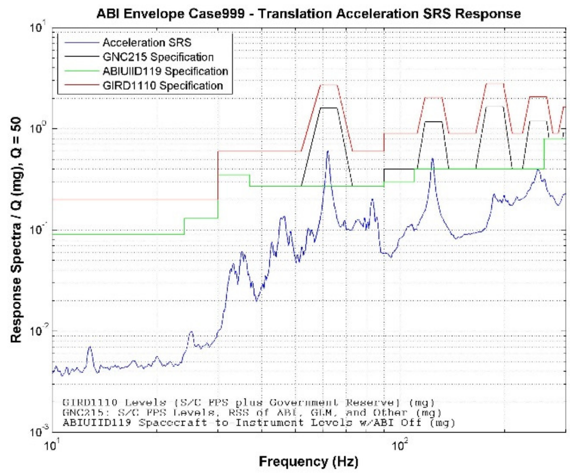


Figure 15. RWA Isolation Only (On-Orbit Result)

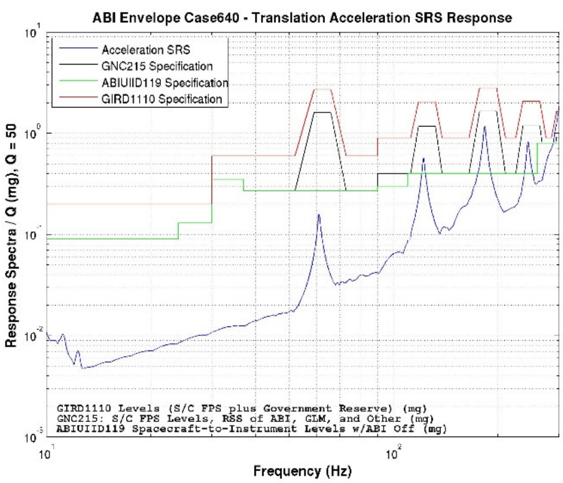


Figure 16. Dual Isolation, Red CC (SIM)

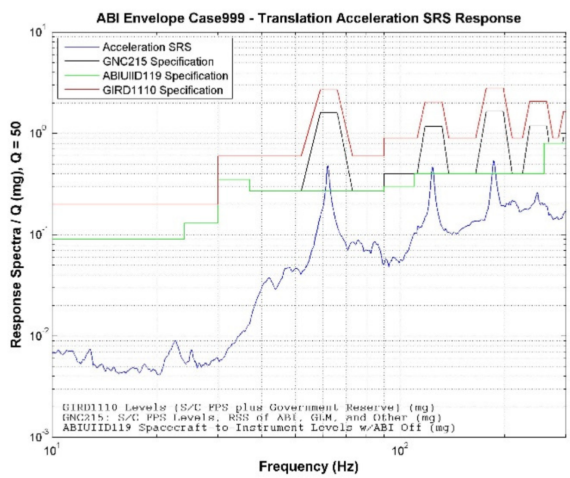


Figure 17. Dual Isolation (On-Orbit Result)

2.4.2 IMU Based Results

Besides the EPP mounted EDAs, data from the EPP mounted IMU was also processed into performance readable form to assess the on-orbit RWA Isolation Only and Dual Isolation configuration DIT performances. The 3-DOF IMU on-orbit DIT results for the two isolation configurations are displayed in Fig. 18-23. The IMU noise floor has thus far precluded gaining insight into the performance difference between the RWA Isolation Only and Dual Isolation configuration DIT performances for the simultaneous combination of ABI, RWAs, LTR, and Arcjet plus other instruments and components operating disturbance environment.

The ABI CC harmonics are evident in the IMU measurements. The processed IMU data was sampled at 100 Hz. The ABI CC first two harmonics are at 62 Hz and 124 Hz. The mechanical motion that results from the ABI CC 62 Hz and 124 Hz harmonics are aliased into the IMU 50 Hz Nyquist frequency band to 38 Hz and 24 Hz, respectively. The EPP payload borne CC disturbance influence on the IMU measurements is seen to result in a slight increase for the Dual Isolation configuration relative to the RWA Isolation Only configuration. This was not an unexpected result and performance margin was allocated against this behavior. The slightly increased IMU measurement results are the result of increased EPP motion at the CC harmonics for the Dual Isolation configuration relative to the RWA Isolation Only configuration. The aliased harmonic frequencies and corresponding amplitudes are such that their impact on INR performance and image quality are insignificant. An artificial data spike produces the wideband spectrum results in the Dual Isolation configuration waterfall plots. This artifact may be ignored since it has no relationship to the mechanically based measured performance results.

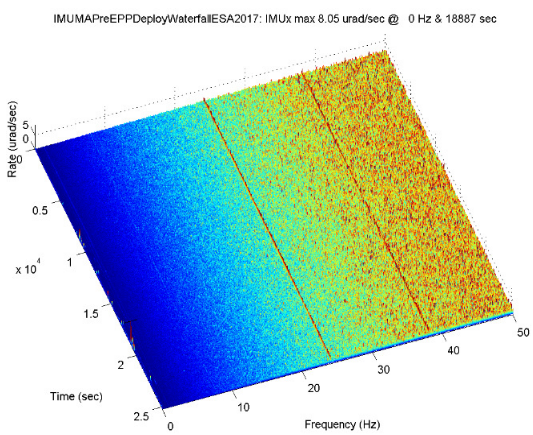


Figure 18. RWA Isolation Only, IMU X-Axis (On-Orbit Result)

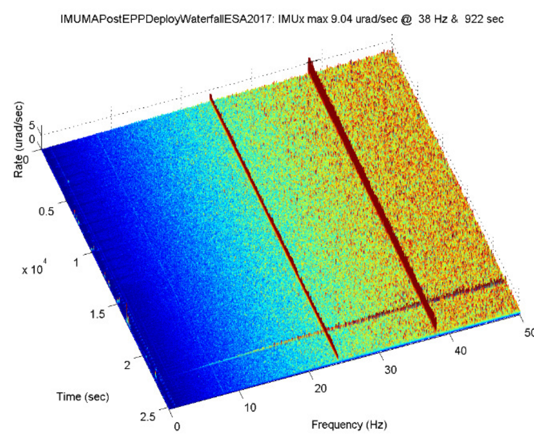
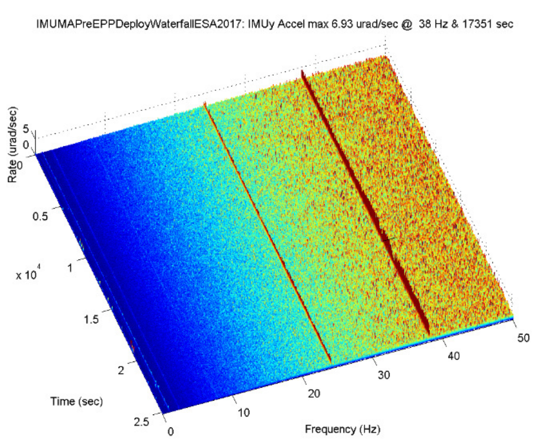


Figure 19. Dual Isolation, IMU X-Axis (On-Orbit Result)



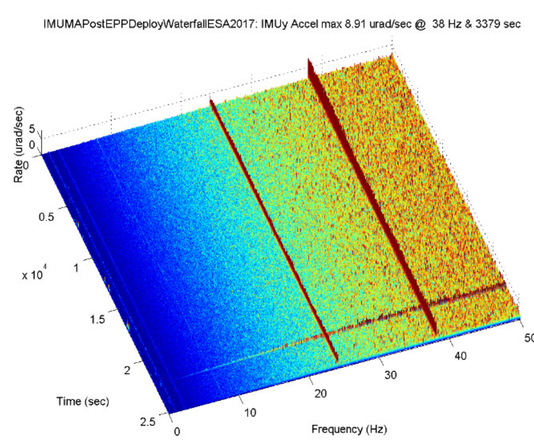


Figure 20. RWA Isolation Only, IMU Y-Axis (On-Orbit Result)

Figure 21. Dual Isolation, IMU Y-Axis (On-Orbit Result)

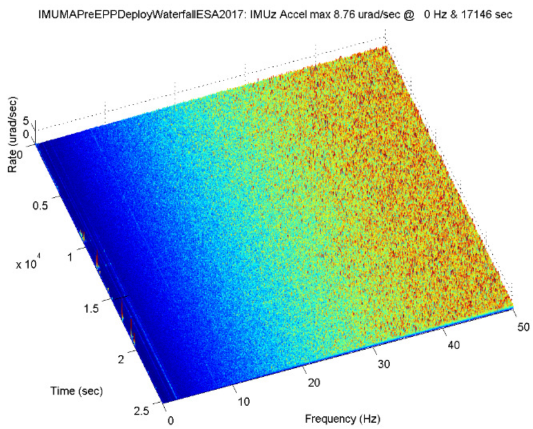


Figure 22. RWA Isolation Only, IMU Z-Axis (On-Orbit Result)

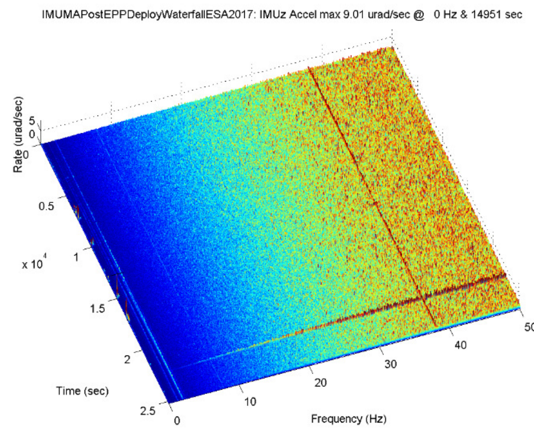


Figure 23. Dual Isolation, IMU Z-Axis (On-Orbit Result)

3 SUMMARY/OBSERVATIONS

To date, some critical on-orbit DIT data has been collected with performance characterization results presented in this paper. However, the on-orbit DIT data collection and processing into performance readable form is currently incomplete. The combined MA/NSSK maneuver is such an event. This maneuver event produces a simultaneous combination of ABI, RWAs, LTR, and Arcjet plus other instruments and components operating disturbance environment. The collected EDAs and IMU data was processed into performance readable form with results presented in this paper. The on-orbit measured DIT results for the RWA Isolation Only and Dual Isolation configurations were compared to each other and to their corresponding analytical model predictions. All results and comparisons were found to be in general agreement with expectations. Besides the on-orbit DIT results, the results from DIT ground testing are also presented in this paper. The ground DIT characterized the DIT performance for the RWA Isolation Only and Dual Isolation configurations over test events that consisted of ABI only operation and RWAs only operation. The ground DIT results were compared to analytical results and to the on-orbit measured DIT results. Again, all results and comparisons were found to be in general agreement with expectations.

Some specific observations are

- The on-orbit Dual Isolation configuration shows reduced "noise floor" disturbance levels generally over the entire frequency range displayed in the plots but especially so for the mid-frequency range of 20-60 Hz relative to the on-orbit RWA Isolation Only configuration.
- A common trend between the analytical model and the on-orbit measured DIT results is the reduction in the ABI CC amplitude at the CC fundamental harmonic for the Dual Isolation configuration relative to the RWA Isolation Only configuration.
- The ABI on-orbit performance results are generally equivalent to or better than the ground

measured results for both the RWA Isolation Only and Dual Isolation configurations.
- There is strong correlation between the ABI ground DIT measured results and the on-orbit DIT measured results.
- The slightly increased IMU measurement results are the result of increased EPP motion at the CC harmonics for the on-orbit Dual Isolation configuration relative to the on-orbit RWA Isolation Only configuration. The IMU aliased CC harmonic frequencies and corresponding amplitudes are such that their impact on INR performance and image quality are insignificant.
- What is evident in the analytical EDA performance predicts is a general increase in the frequency spectrum amplitude with increasing frequency that is not as strongly evident for the on-orbit EDA measured DIT results.

4 ACKNOWLEDGMENT

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5 REFERENCES

[1] D. Freesland, D. Carter, J. Chapel, B. Clapp, J. Howat, A. Krimchansky, *GOES-R Dual Isolation*, Proceedings of the 38th Annual AAS Rocky Mountain Section Guidance and Control Conference, January 2015.

[2] J. Chapel, D. Stancliffe, T. Bevacqua, S. Winkler, B. Clapp, T. Rood, D. Gaylor, D. Freesland, A. Krimchansky, *Guidance, Navigation, and Control Performance for the GOES-R Spacecraft*, Proceedings of the 9th International ESA Conference on Guidance, Navigation & Control Systems, June 2014.

[3] L.P. Davis, D.R. Carter, T.T. Hyde, *Second-Generation Hybrid D-Strut*, Proc. SPIE 2445, Smart Structures and Materials 1995: Passive Damping, 161, May 1995.

[4] M. Brzowski, *EPP Shunted Transmissibility Results*, Lockheed Martin Presentation, March 5, 2013.

[5] *GOES-R General Interface Requirements Document (GIRD)*, 417-R-GIRD-0009, Version 2.33, July 29, 2013.

[6] *GOES-R Series Payload Resource Allocation Document (PRAD)*, 417-R-RAD-0061, Version 2.21, June 14, 2013.